Design of freestanding film elements for HVM tools of EUV nanolithography

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Outline

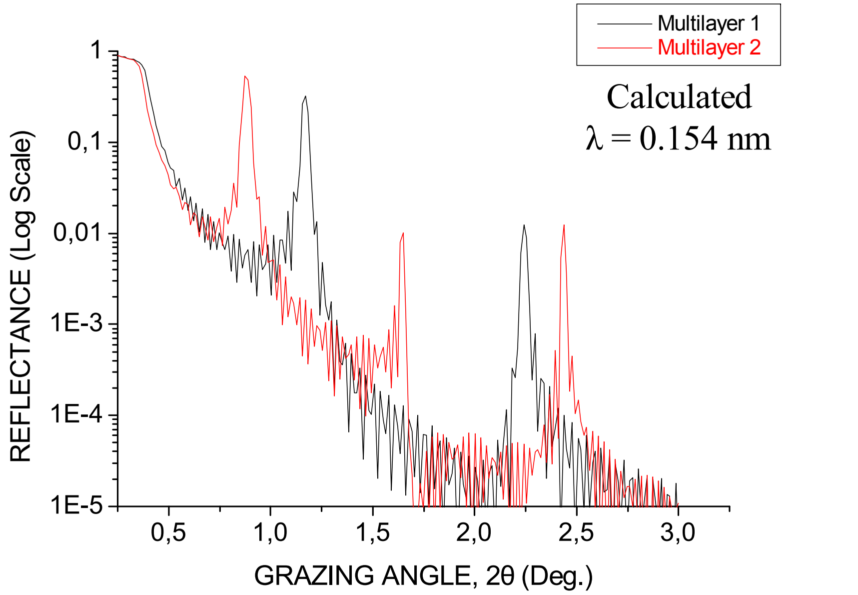
- **Magnetron sputtering and characterization of thin films**
- **Simplified approach to fabrication of freestanding multilayers, its possibilities and limitations**
- **Mechanical and optical properties, heat load withstandability of film spectral purity filters for EUV nanolithography**
- **Improved technique of freestanding membrane fabrication**
- **Thin film pellicles and SPF DGL: fabrication status**

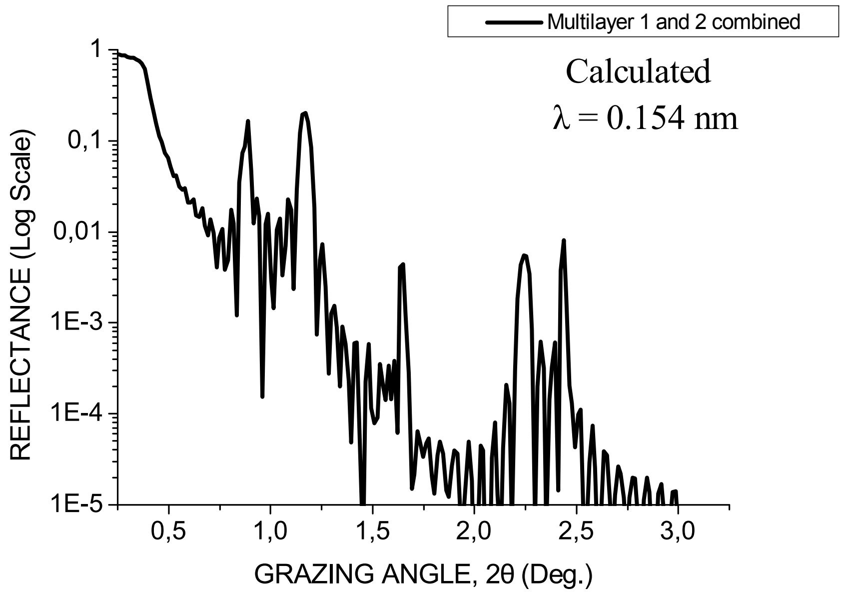
Magnetron deposition and measurements

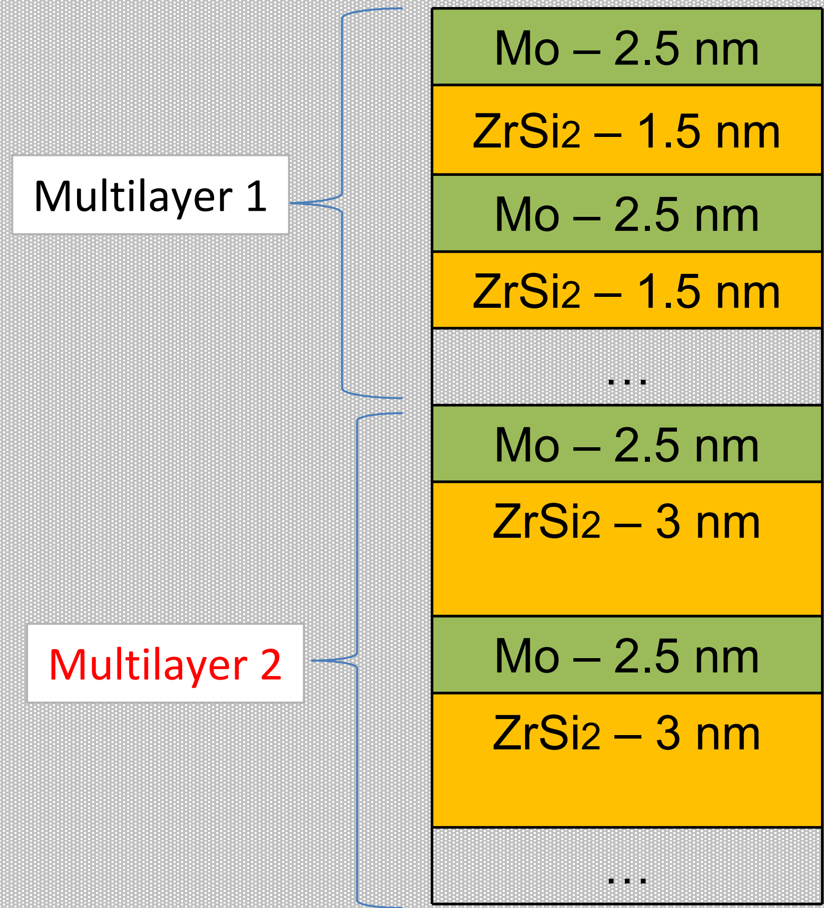
Up to 6 various materials can be combined in one multilayer structure

Measurements of deposition rates

PANanalitical X'Pert PRO (λ = 0.154 nm)







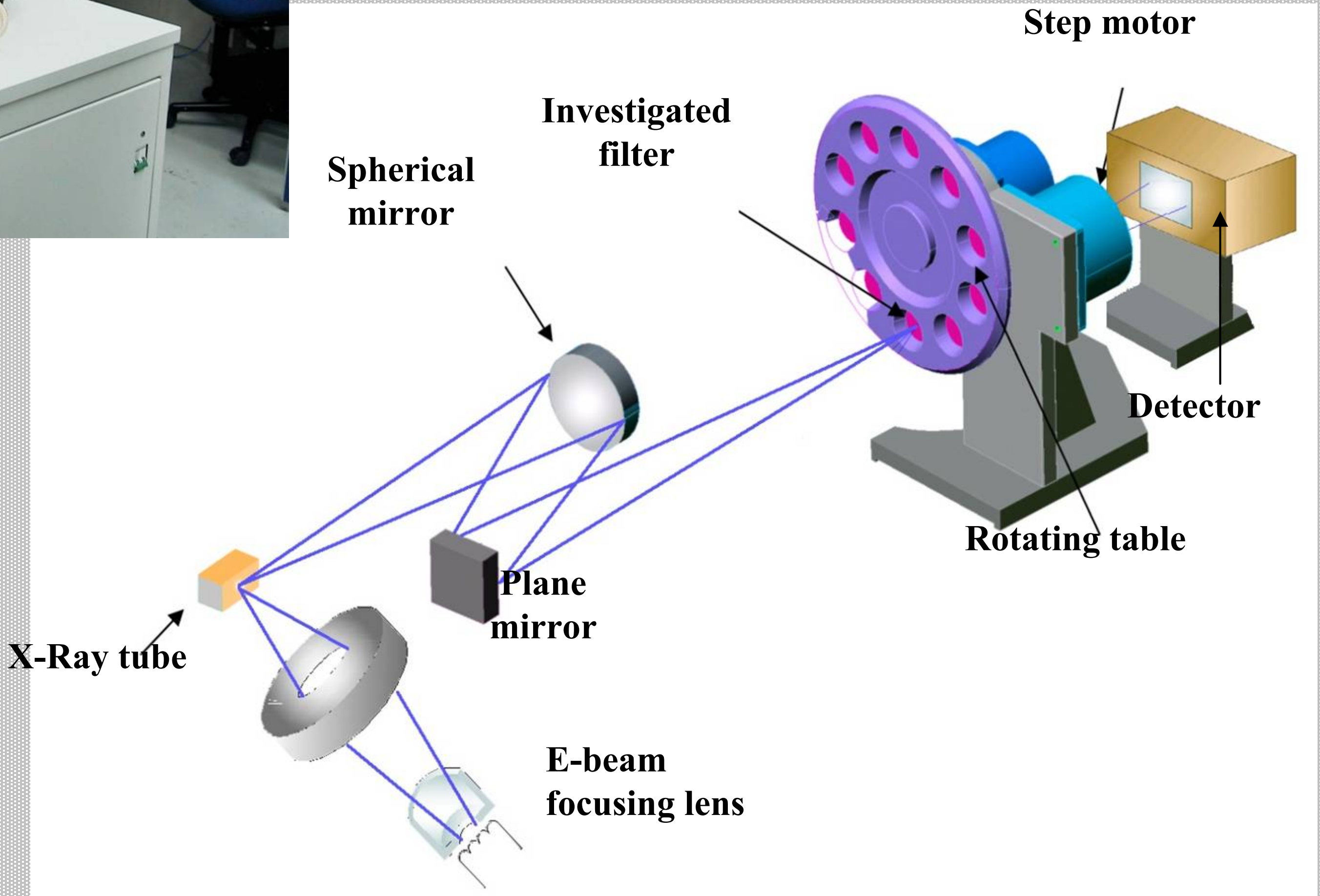
$d=d(Mo)+d(ZrSi_2)$

$2d \sin(\Theta max) = n\lambda$, n=1,2,..

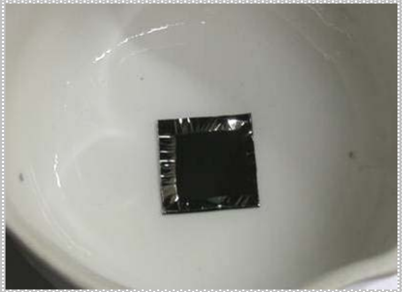
d(layer)=r*t, where r – deposition rate,
t – deposition time

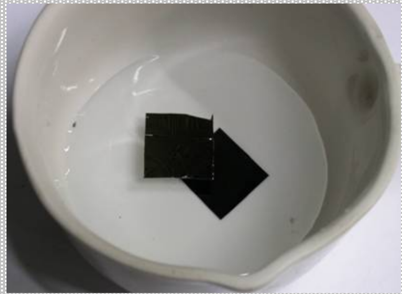
Sketch of transparency measurements at λ = 13.5 nm

Double mirror EUV reflectometer



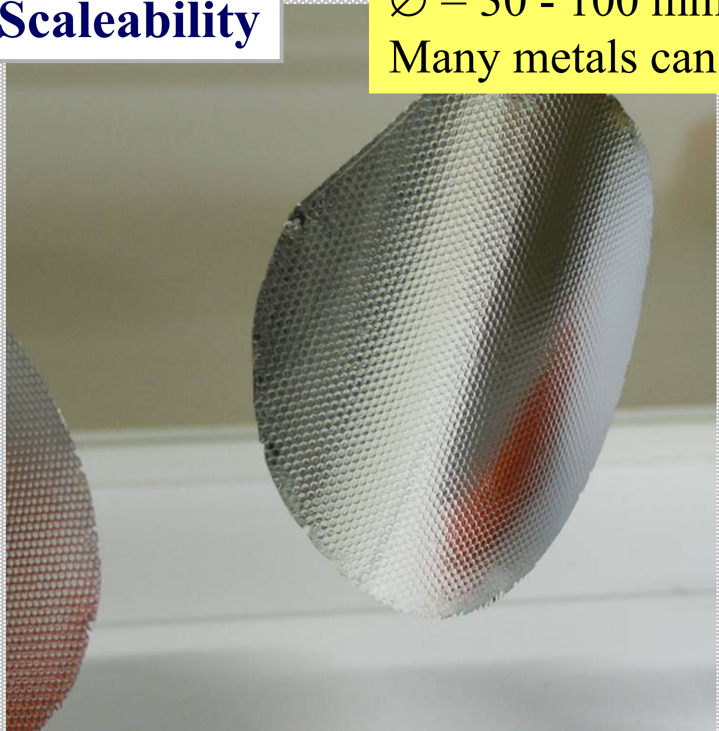
Basic approach to fabrication of freestanding multilayers



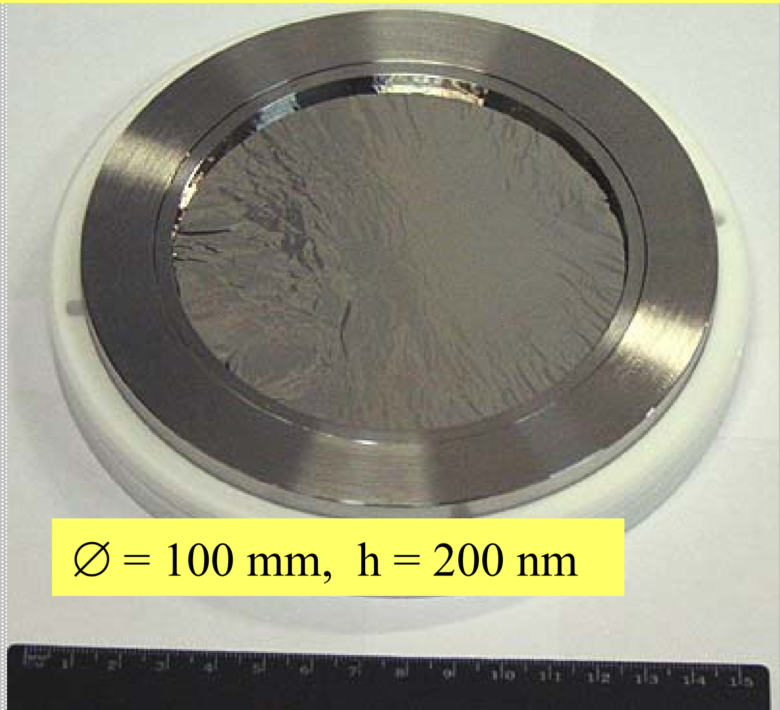


Scaleability

∅ = 30 - 100 mm, h = 100 - 200 nm, T = 40 – 50% at λ = 13 nm
Many metals can be used as main material in multilayer films

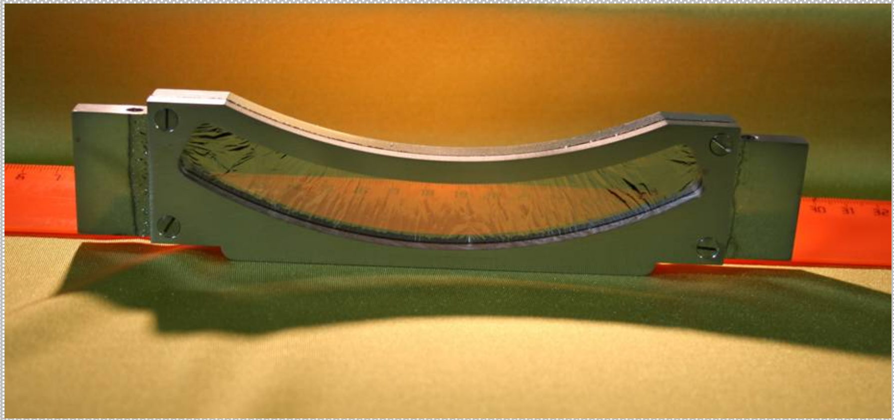


Design of films with electroplated mesh



∅ = 100 mm, h = 200 nm

Large aperture SPF for EUV lithography



Zr/Si, N = 23, d = 2.2 nm,

β = 0.73, h = 50 nm

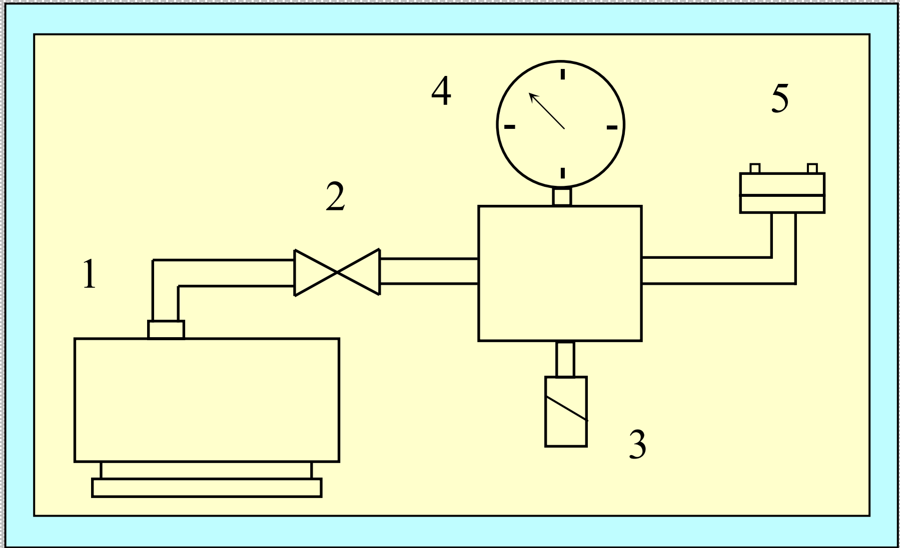
20×140 mm^2 T = 76%

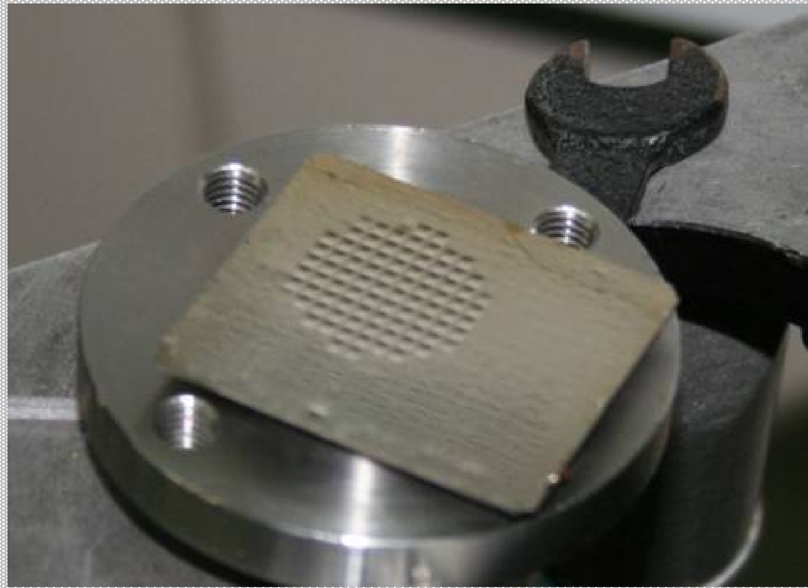
shipped 2006-2007

(Zr-2.8 nm, $ZrSi_2$-1.25 nm)*22.5

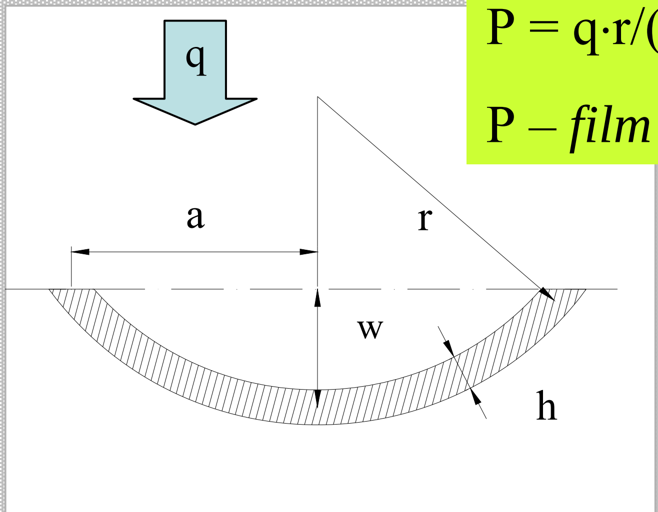
∅160 mm T = 65% shipped 2010-2011

Mechanical strength of samples



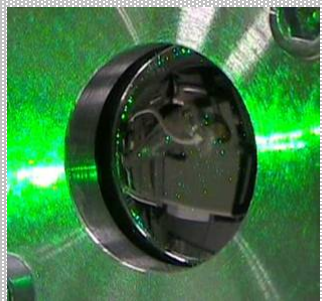


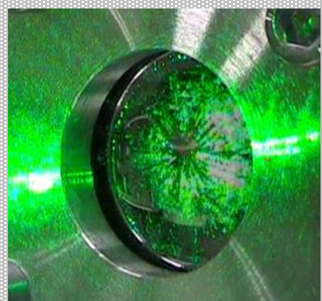
1 – vacuum pump, 2 – pump valve, 3 – leak valve, 4 – manometer, 5 – sample holder

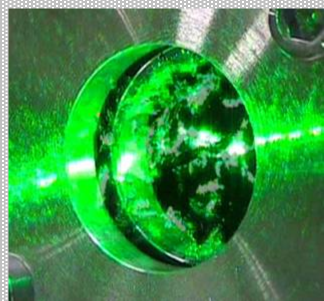


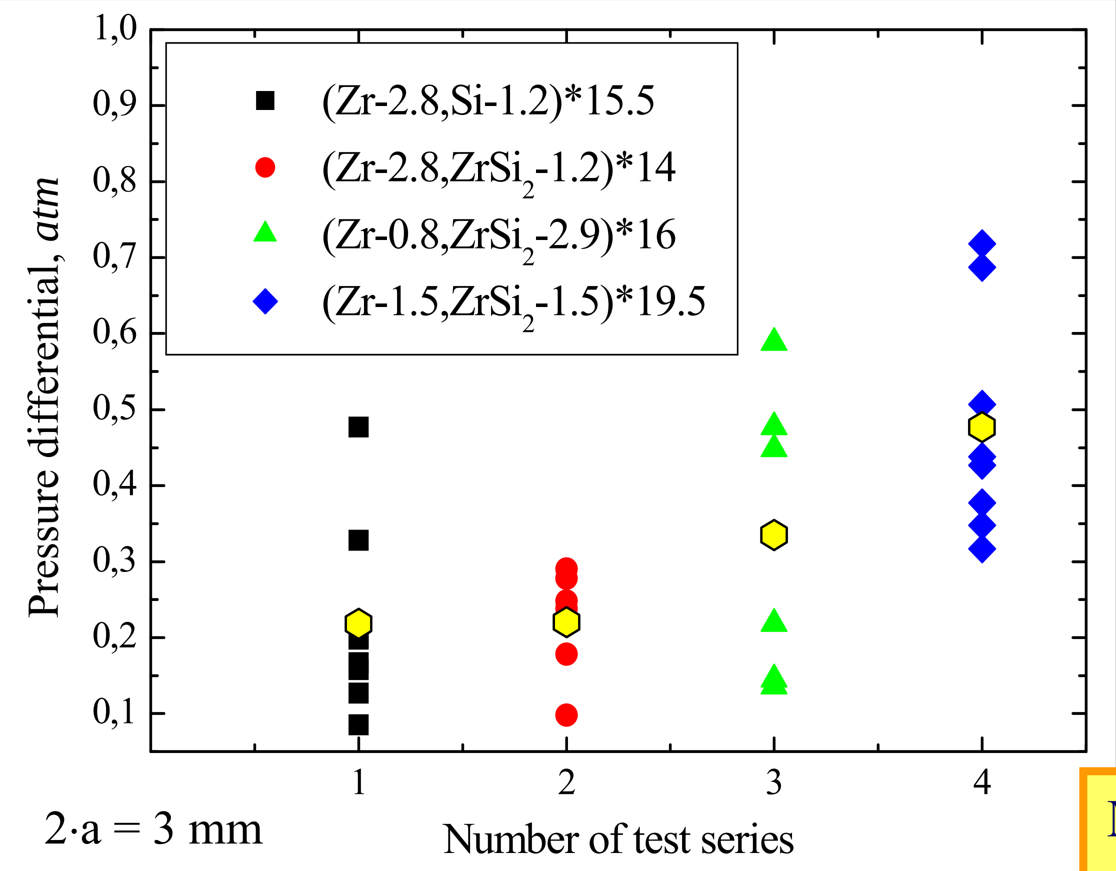
$P = q \cdot r/(2 \cdot h)$ $r = a^2/2 \cdot w$ $w = (a^4 \cdot q \cdot (1-\mu)/(4 \cdot E \cdot h))^{1/3}$

P – *film stress* μ - *Poisson's ratio* E – *Young's modulus*









Film composition	Thickness, nm	q, atm
Mo	45	0.09
Mo	60	0.24
Zr	100	0.22
$Zr/ZrSi_2$	60	0.72
$Mo/MoSi_2$	51	0.62

Multilayer films are superior to monolayers and bulk materials in mechanical strength

$Zr/ZrSi_2$ (r = 5.4 mm at q = 0.7 atm) → P_{lim} = 2.1 GPa $E = 2\cdot10^3$ GPa

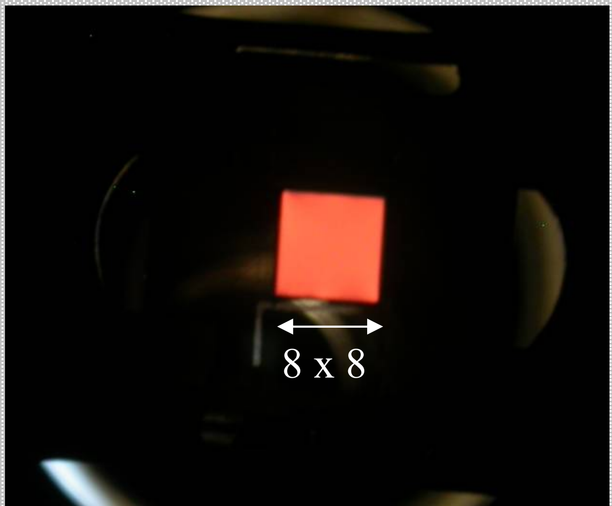
Zr, bulk (tabular data) P_{lim} = 0.25 GPa $E = 10^2$ GPa

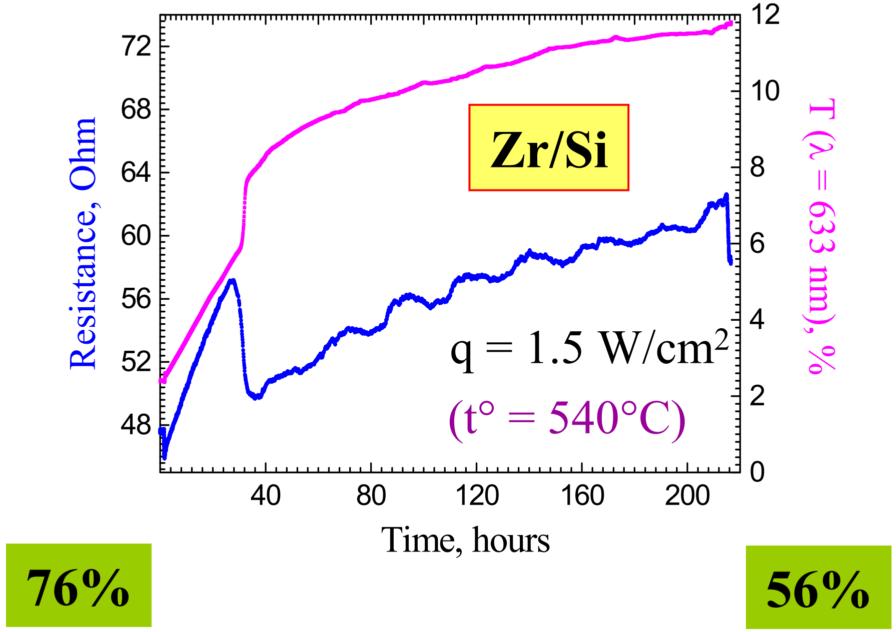
Choice of material composition

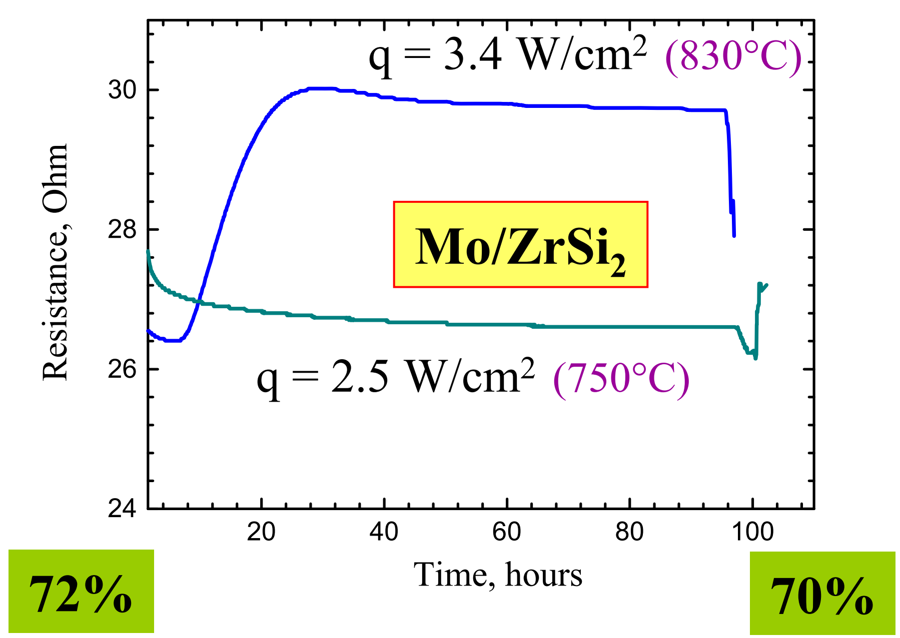
Structure, thicknesses in nm	λ = 10.6 µm		λ = 633 nm	λ = 13.5 nm	
	R, %	*T*, %	*T*, %	T_{th}, %	T_{exp}, %
(Zr-1.6, Si-0.6)*25	71.0	-	2.3	84.5	75.0
$ZrSi_2$-6, (Zr-1.5, $ZrSi_2$-1.5)*17, Zr-1.5, $ZrSi_2$-6	76.0	1.93	0.87	81.0	73.6
(Zr-2.8, $ZrSi_2$-1.25)*15	76.3	2.15	1.1	81.2	72.5
Zr-100	85.2	0.27	0.029	69.9	62.3
(Mo-1.6, Si-0.6)*23	80.5	1.5	0.54	77.1	70.0
$MoSi_2$-3, (Mo-2.5, $ZrSi_2$-1.5)*11, Mo-2.5, $MoSi_2$-3	85.1	0.85	0.70	76.4	70.7
Mo-60	91.7	0.15	0.025	67.4	65.2

Heat load tests

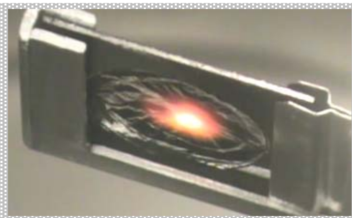
Heating by electrical current

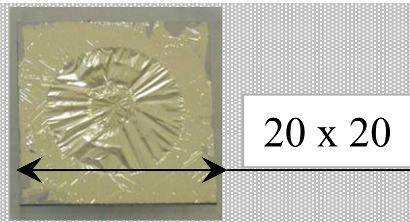






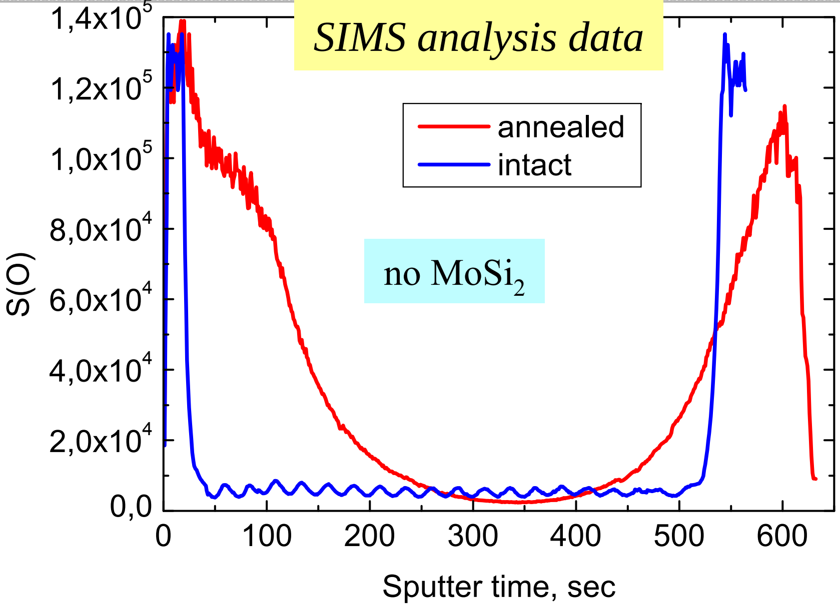
Heating by laser irradiation

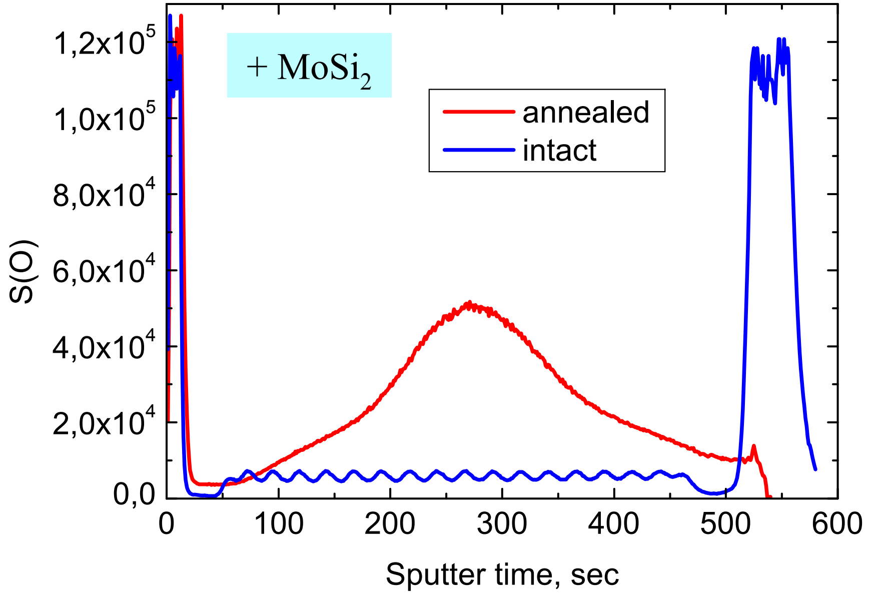




Structure (thicknesses in nm)	t °C	τ, h	T_i, %	ΔT, %
(Zr-1.5,$ZrSi_2$-1.5)*19.5	700 – 740	4	74.5	7.3
$MoSi_2$-6,(Zr-1.5,$ZrSi_2$-1.5)*17.5,$MoSi_2$-6	920 – 940	4	73.4	4.8
$ZrSi_2$-6,(Zr-1.5,$ZrSi_2$-1.5)*17.5,$ZrSi_2$-6	950 – 980	3.5	73.6	9.2
(Mo-2.5,Si-1.0)*14.5	690	1.5	72.3	4.5
$MoSi_2$-3.1,(Mo-2.5,Si-1.0)*12.5, $MoSi_2$-3.1	710-745	3	74.3	1
(Mo-2,$MoSi_2$-3)*10.5	700 – 740	4	70.9	< 0.3

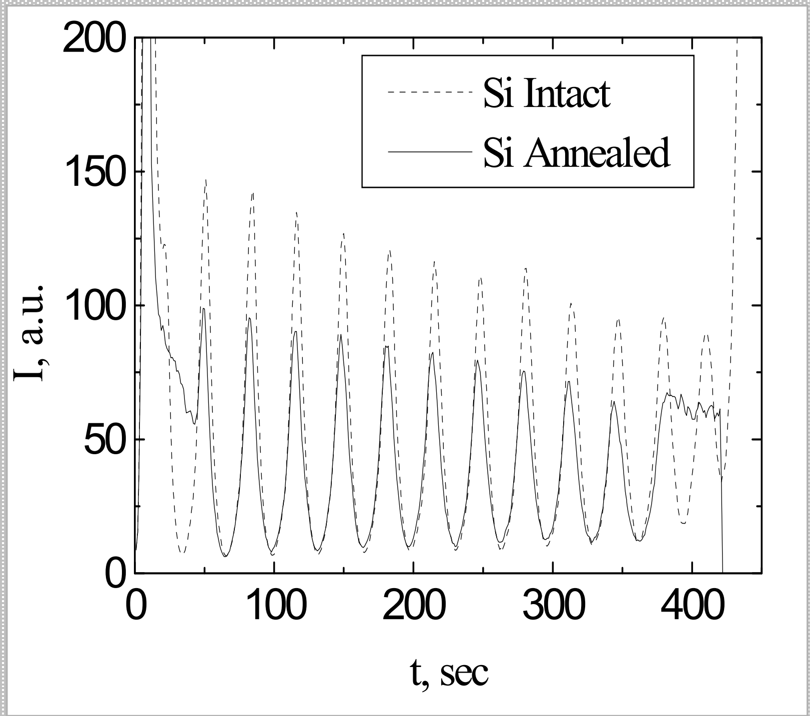
SIMS analysis data

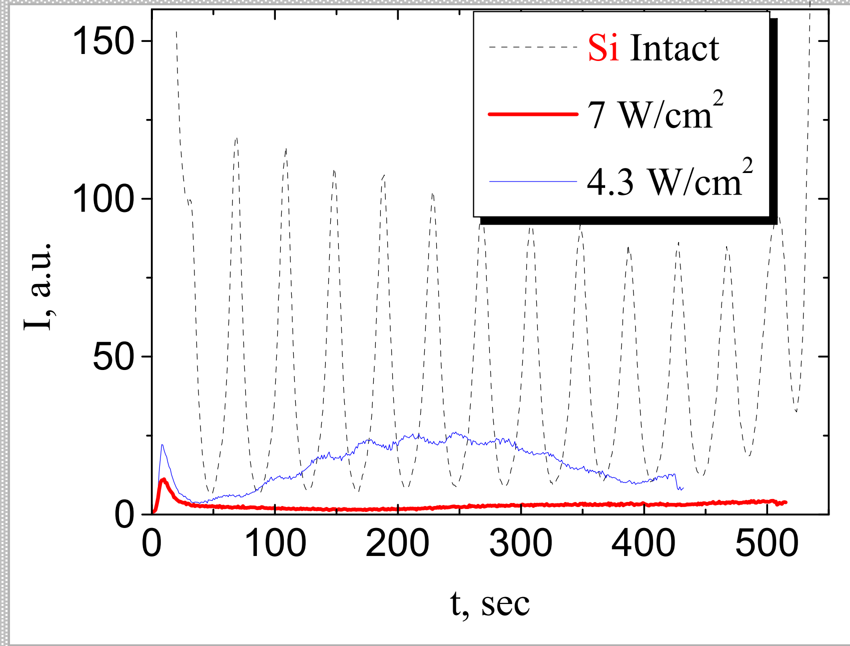


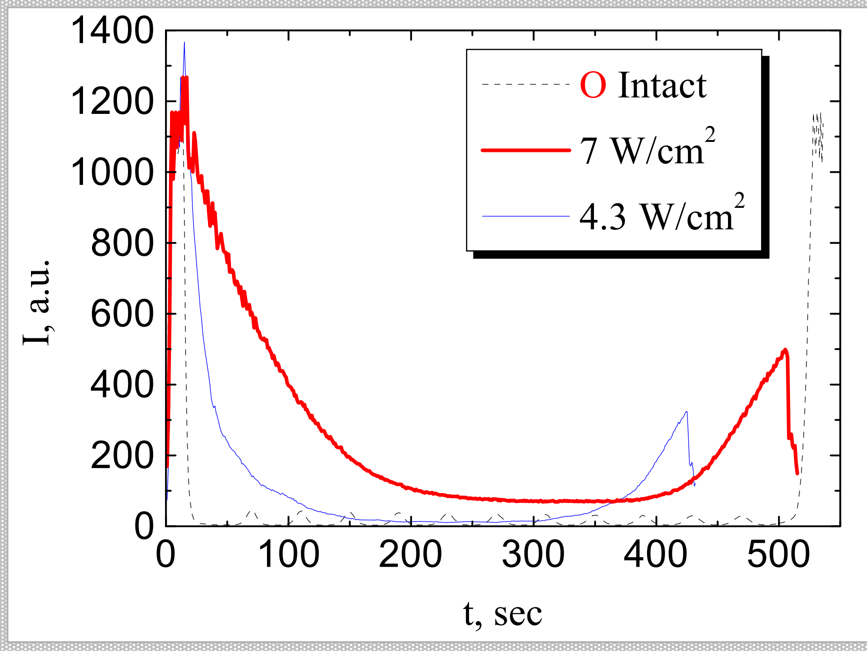


$MoSi_2$-3.3,(Mo-2.5,$ZrSi_2$-1.5)*11.5, $MoSi_2$-3.3

τ = 7.5 h, 900°C, 1000°C



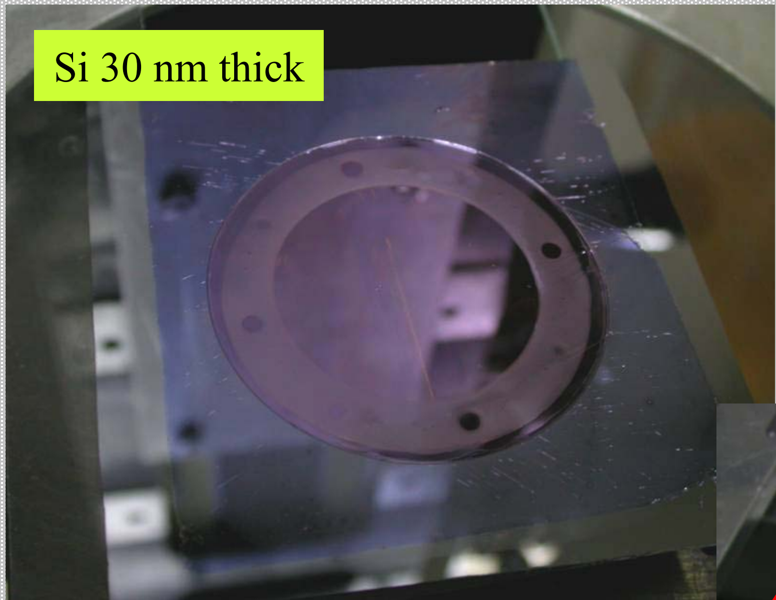




τ = 3 h, 780-800 °C – no optical changes

λ, nm	Intact	1000°C, 7.5 h	Annealed
13.5	70.6%	⇨	65.8%
633	0.8%		2.3%
10600	1%		0.5%

“Plasticization” of thin films

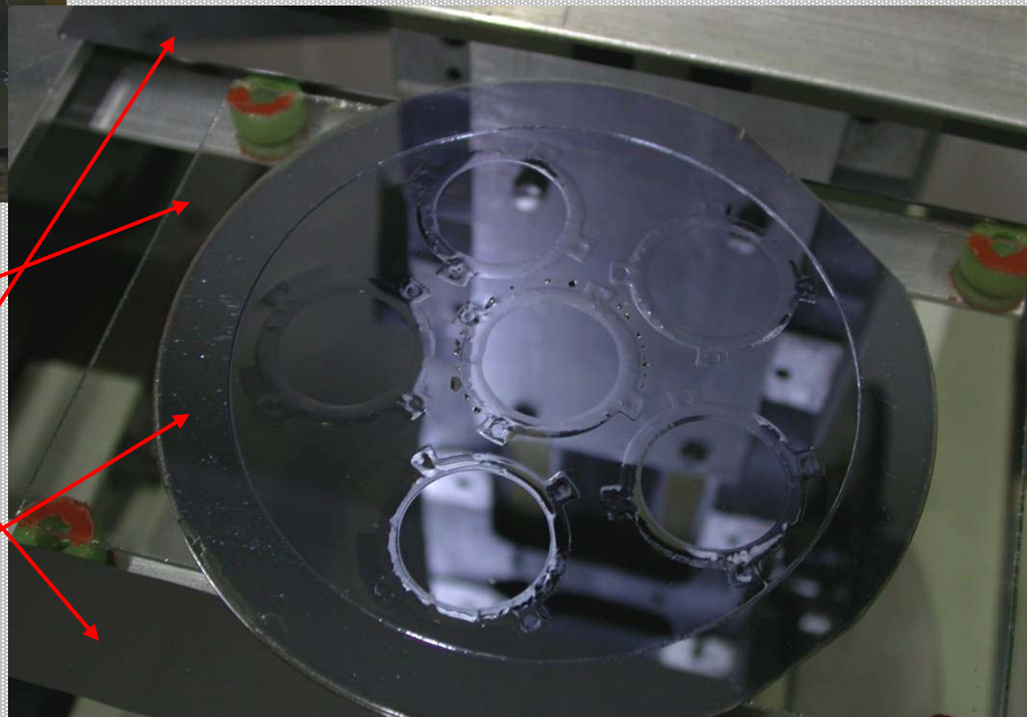


Fabrication of large film samples from stiff materials (like Mo) and gluing of 25 – 30 nm (and probably more thin) films to frames becomes possible with the technique of strengthening by polymer layer

Glass stage with glued details

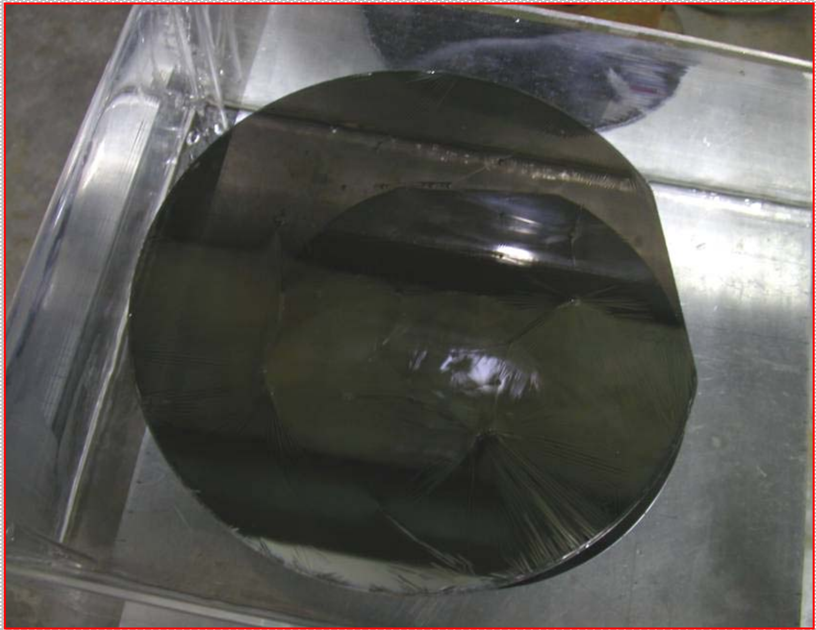
Bearing assembly of Si ring

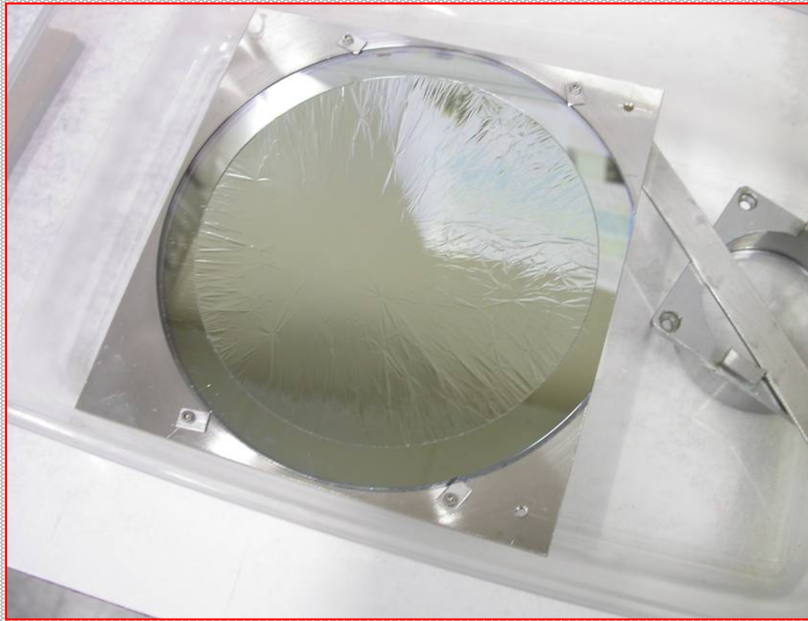
Si ring with (polymer coated) stretched film ∅80

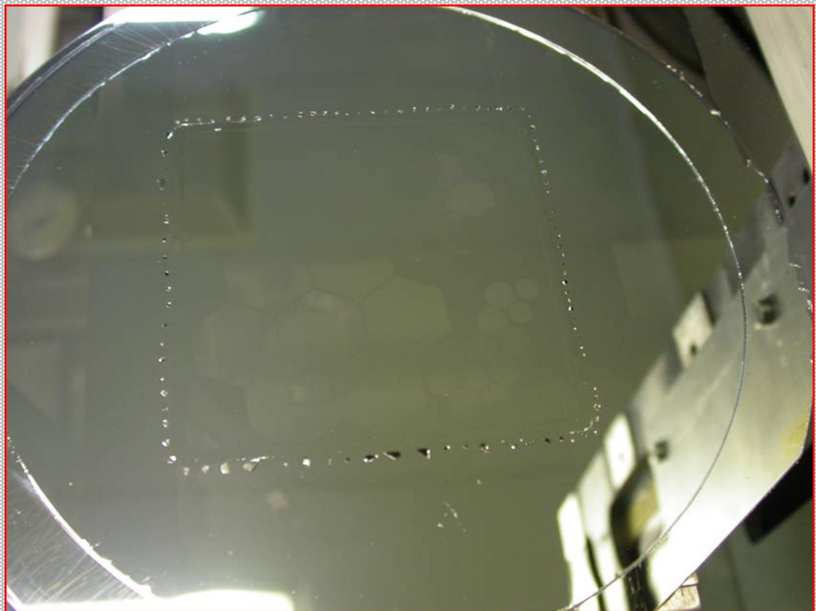


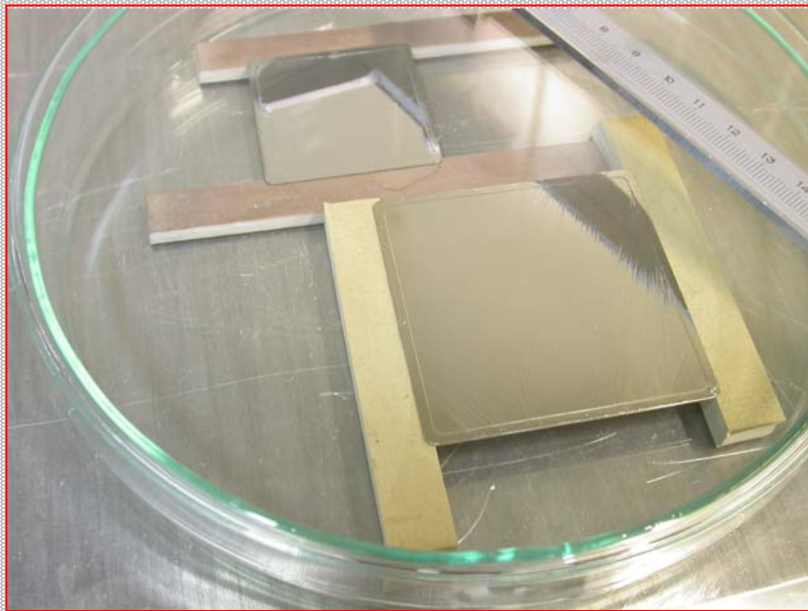
$MoSi_2$-3.3,(Mo-1.0,$ZrSi_2$-1.5)*7.5, $MoSi_2$-3.3

Example: session of 25 nm thick Mo/$ZrSi_2$ film sputtered onto 150-mm substrate









To be improved in future performance

Quality

Quantity

Membrane inspection, statistics on contaminants

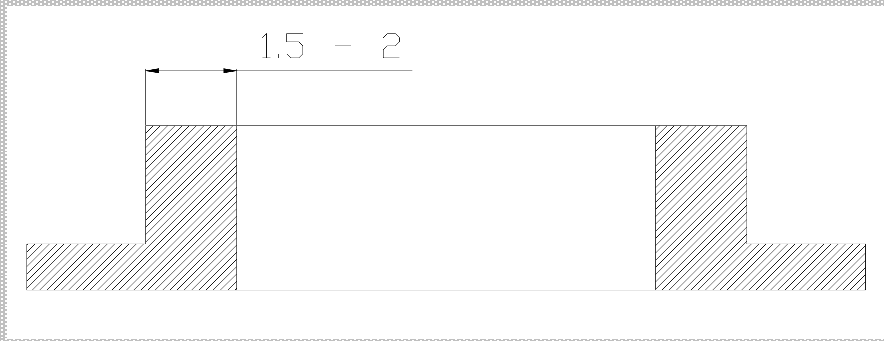
Etching in hermetic vessel (no contamination from room environment)

Proper structure of the edge of the film (no contamination by fragments of own edge)

Fast smearing with epoxy

Stretching using dispense controller

Optimization of the frame design to provide fine positioning of frames at gluing and minimal impact on thin film



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Thank you for attention!